

RESEARCH DEPARTMENT

A TRANSPORTABLE BAND II F.M. RECEIVER FOR STUDYING
MULTIPLE PROPAGATION PATHS

Report No. G-072

(1959/2)

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Section	Title	Page
	SUMMARY	1
1	INTRODUCTION	1
2	DESCRIPTION OF RECEIVER	1
	2.1. General Description	1
	2.2. Description of Circuit	3
3	OPERATING INSTRUCTIONS	5
	3.1. Description of Controls	5
	3.2. Summary of Operating Procedure	7
	3.3. Interpretation of Display	8
4	PERFORMANCE	9
	4.1. Sensitivity	9
	4.2. A.M. Suppression Ratio	10
	4.3. Modulation-Frequency Response	10
	4.4. Total Harmonic Distortion	10
	4.5. Frequency Response of Oscilloscope Display	10
5	CONCLUSIONS	11
6	REFERENCES	11

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SUMMARY

This report describes a transportable Band II f.m. receiver which provides both an audio-frequency output to an internal or external loudspeaker, and a visual display of the amplitude/frequency characteristic of the propagation path of the received signal. It was designed to assist in the investigation of the incidence and effects of multipath propagation in f.m. broadcasting.

1. INTRODUCTION

In a radio communication system the signal at the receiving site will generally consist of a direct signal from the transmitter and one or more delayed signals which have been reflected from near or distant objects. In the case of a frequency-modulated transmission this multipath propagation causes phase and amplitude modulation of the carrier, giving rise to perceptible distortion of the reproduced programme if the time delays and relative amplitudes of the reflected signals are sufficiently large.^{1, 2}

The receiver described provides an oscilloscope display of the received signal amplitude as a function of instantaneous carrier frequency; from this it is possible to deduce the magnitudes and path differences of the principal delayed signals.¹ The display is also most useful when adjusting the position of the receiving aerial to obtain the maximum ratio of direct to reflected signals.

Although the apparatus is intended for use in observing the effects of multipath propagation on transmissions of broadcast programmes, there are certain limitations, discussed in Section 3.3, of the accuracy of the display in these conditions. It is most easily interpreted if the transmission to be observed can be frequency modulated to its nominal peak deviation at a low audio frequency, say between 100 c/s and 150 c/s.

The degree of limiting in the receiver is sufficient to ensure that the distortion in the audio output resulting from multipath propagation is almost entirely that associated with the phase modulation component of the complex signal, the a.m. component being effectively suppressed.²

2. DESCRIPTION OF RECEIVER

2.1. General Description

The receiver, which is shown in Fig. 1, comprises a tuner unit, oscilloscope, audio-frequency amplifier, power supply, and loudspeaker; it incorporates a signal-

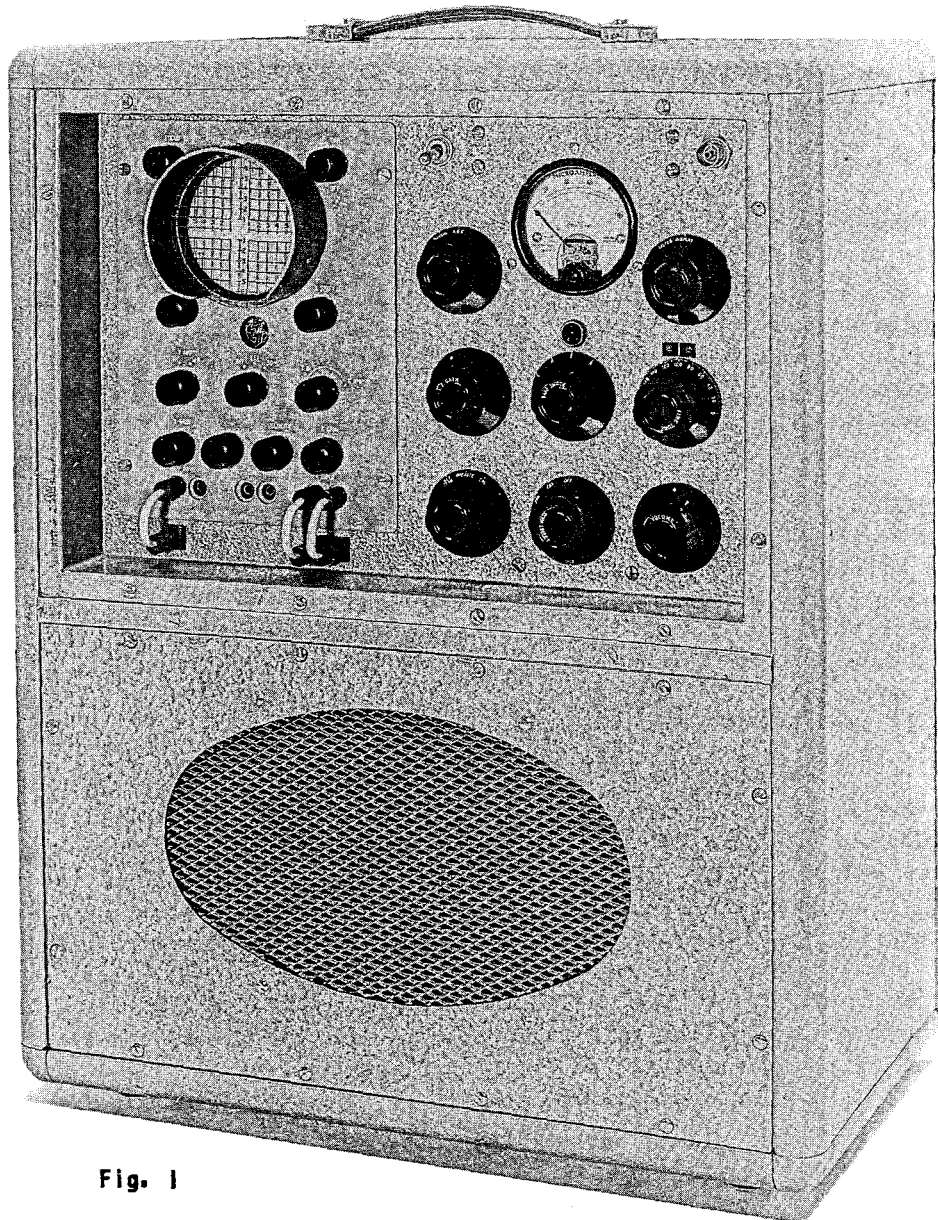


Fig. 1

strength meter, and is tunable over a range which covers the Band II frequencies at present in use in the United Kingdom. The equipment is enclosed in a metal case with carrying handle; a removable front panel covers the controls, loudspeaker grille and tube face, to protect them from damage in transit.

Dimensions

21 in. high x 16½ in. wide x 9½ in. deep (53 cm x 42 cm x 24 cm)

Weight

47 lb (21.3 kg)

Power Requirements

100 W at 200/250 V, 40/100 c/s a.c.

Frequency Coverage

88 Mc/s - 97 Mc/s

External Connections

Input: 75 ohms, unbalanced.

Output: (1) low impedance, delivering approximately 1.5 W to an external 3-ohm loudspeaker.

(2) 600 ohms, delivering approximately 2 mW to an external 600-ohm load.

2.2. Description of Circuit

A block schematic of the equipment is shown in Fig. 2 and a circuit diagram in Fig. 3. Interconnection between the various units and the main framework carrying the control panel is by plugs and sockets.

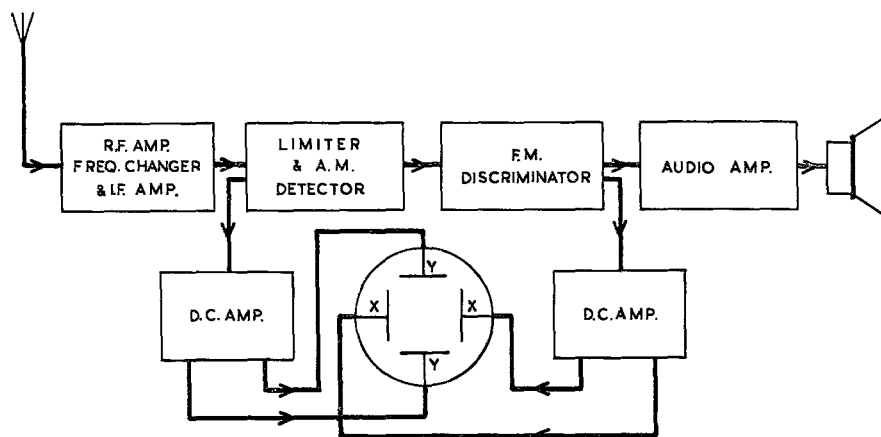


Fig. 2 - Block schematic diagram

The oscilloscope is a standard commercial product, (E.M.I. Electronics, type 2300) and is not described in this report.

The tuner is basically a Dynatron type FM2.LV. which has been modified to provide the various outputs and controls required for the oscilloscope display; the power supply and audio amplifier are of conventional design. The tuner, amplifier and power supply employ eleven valves, the types and functions of which are given in Table 1.

The X deflection voltage for the oscilloscope is obtained from the discriminator output of the tuner, and the Y deflection voltage from the control-grid potential of the limiter valve V6. Both of these circuits are d.c. coupled. The horizontal deflection of the oscilloscope indicates the instantaneous frequency of the received carrier and the vertical deflection its amplitude.

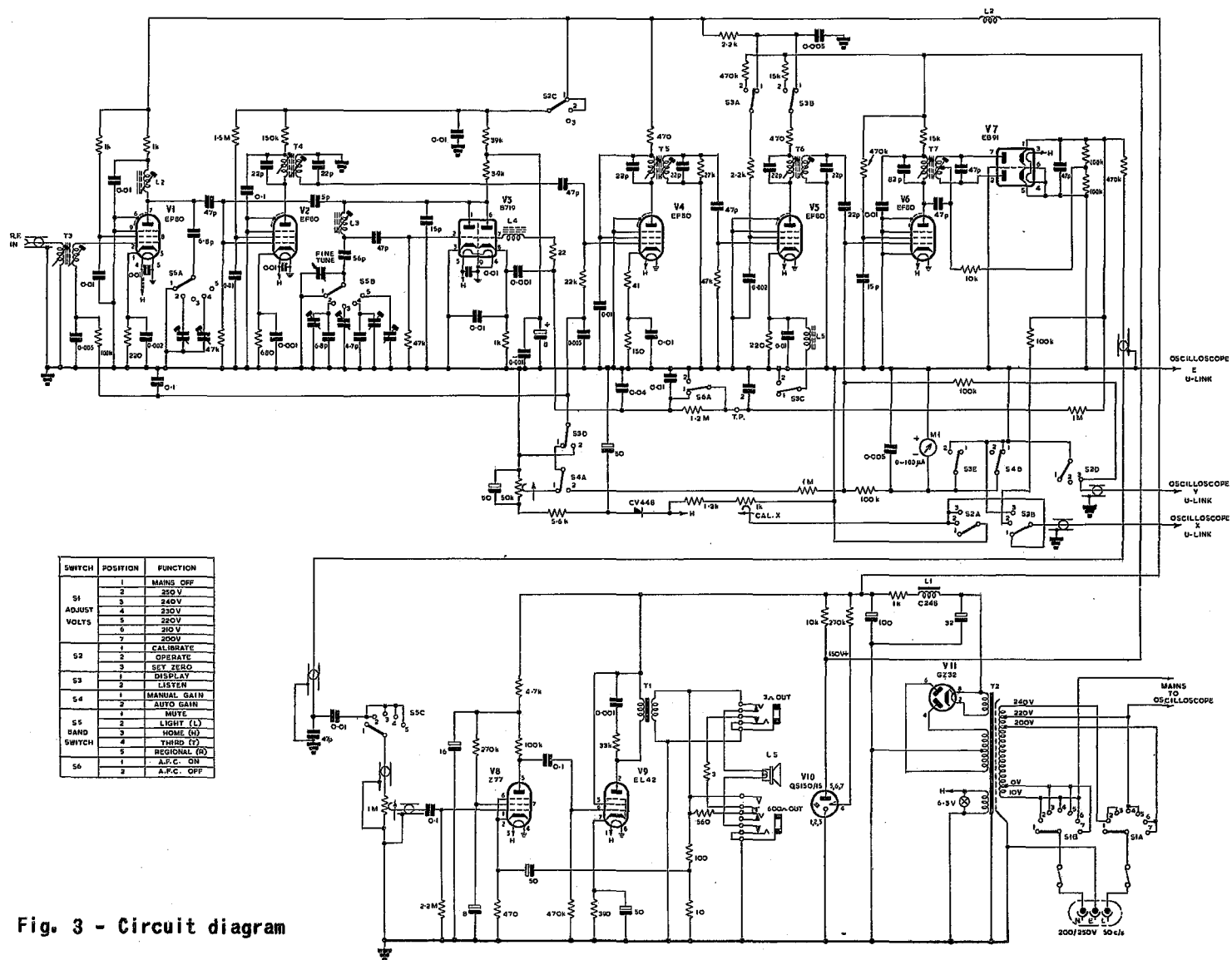


Fig. 3 - Circuit diagram

TABLE 1

Valve	Type	Function
V1 EF80	r.f. pentode	r.f. amplifier
V2 B719	double-triode	local oscillator and a.f.c. reactance valve
V3 EF80	r.f. pentode	mixer
V4 EF80	r.f. pentode	i.f. amplifier
V5 EF80	r.f. pentode	i.f. amplifier or limiter
V6 EF80	r.f. pentode	limiter
V7 EB91	double-diode	discriminator
V8 Z77	r.f. pentode	audio amplifier
V9 EL42	output pentode	audio output
V10 QS150/15	neon stabiliser	h.t. stabiliser
V11 GZ32	rectifier	h.t. rectifier

In its original form the tuner has two stages of amplitude limiting, (V5 and V6), but the circuit has been modified so that V5 can be switched to function as a linear amplifier when using the oscilloscope display. Since in this condition there is only one limiter, the valve operating conditions have been changed to improve the efficiency of limiting.

An a.g.c. circuit has been added but this can be switched out and the receiver operated with manually controlled i.f. gain if required.

The original tuning system was a four-position switch which selected pre-set capacitance trimmers for pre-determined frequencies. In order to permit rapid retuning to any channel in Band II, a continuously variable control has been added in the local-oscillator circuit, with a range sufficient to cover the interval between adjacent switched frequencies; thus the band is covered in four ranges, each roughly 2.5 Mc/s wide.

A meter is provided to indicate the approximate signal input level by measurement of the grid current of the limiter valve V6. No steps have been taken to maintain a high order of gain stability in the tuner, but the short-term accuracy of this indication should be within ± 6 dB.

In order to avoid phase distortion of the oscilloscope display at low modulation frequencies, the time constant of the a.f.c. circuit has been increased to 1 second. This modification makes tuning tedious as a result of the rather sluggish action of the a.f.c. in tending to compensate for tuning adjustments. A switch has therefore been added so that the a.f.c. can be disconnected when tuning.

3. OPERATING INSTRUCTIONS

3.1. Description of Controls

Display/Listen Switch

For normal operation this is set to "Display"; the "Listen" position brings into operation an additional stage of amplitude limiting which may be found

advantageous when listening under conditions of severe interference. In the "Listen" position, however, the carrier-level meter is disconnected and the oscilloscope display may be non-linear and should be disregarded.

A.G.C./Manual Switch and I.F. Gain Control

For normal operation the receiver is switched to "A.G.C." and the "I.F. Gain" control is inoperative. In this condition the meter indicates the input signal level over the range of 20 μ V to 100 mV, and the oscilloscope display of amplitude modulation is linear up to input levels of at least 10 mV.

In the "Manual" position, the a.g.c. circuit is disconnected and the receiver gain is controlled by the "I.F. Gain" control, the carrier-level meter being rendered inoperative. The oscilloscope display is then linear in regard to both audio-frequency a.m. and slow changes of carrier level. This method of operation is useful when it is required to photograph or trace the oscilloscope display. In certain conditions of multipath propagation the mean signal strength varies appreciably with the deviation; if these variations are partially compensated by a.g.c. action, the trace will jitter up and down with the programme modulation. Fixed gain operation is also helpful when assessing the amplitude of the slow fluctuations of signal level resulting from aircraft reflections.

When operating on manual gain control it is essential that the i.f. gain potentiometer be not set at too high a level, as this may result in overloading of the i.f. amplifier. This can be avoided by first setting up the receiver on a.g.c., then switching to manual control and adjusting the i.f. gain to give the same vertical deflection of the oscilloscope trace.

Set Zero/Operate/Calibrate Switch

This switch is provided to facilitate adjustment of the oscilloscope controls. In the "Set Zero" position the X and Y inputs to the oscilloscope are removed, enabling the shift controls to be adjusted to centre the spot horizontally and to set it vertically at any desired zero base line. Switching to "Calibrate", injects into the X amplifier a 50 c/s sinusoidal voltage equal to the output of the receiver with ± 75 kc/s deviation, thus enabling the X gain control to be adjusted. It should be noted that the gain and shift controls are slightly interdependent.

When these adjustments have been made the switch is returned to the "Operate" position.

Tuning Controls

The total tuning range is divided into four bands, selected by the four-position switch "Coarse Tune" which switches pre-set trimmer capacitors across the r.f. amplifier and local-oscillator circuits. The "Fine Tune" control is a variable trimmer in the local-oscillator circuit and has a range sufficient to cover each band with a small overlap.

A.F.C. Switch

This control enables the a.f.c. to be removed from the local oscillator.

When the receiver is switched on, the local-oscillator frequency changes appreciably during the initial valve warm-up period of about one minute and the receiver may lock on to some signal other than the one to which it is nominally tuned. This effect can be obviated by momentarily switching off the a.f.c. a minute or two after the receiver is switched on.

It is also advisable to switch out the a.f.c. when tuning; this avoids the possibility of leaving the receiver tuned to the wrong channel. In addition, any small errors in tuning are reduced to a negligible level when the a.f.c. is restored.

The functions of the remaining controls on the front panel are self-explanatory; the sync. switch on the oscilloscope should be left in the "Ext." position, the "Y Amp." switch set to "D.C." and the time base switch set to "X Amp.". If the apparatus is used for listening only, the oscilloscope can be switched off by the mains switch, which is ganged to the brilliance control.

Cal. X Control

This is a pre-set potentiometer on the rear panel which controls the amplitude of the 50 c/s X calibrating voltage. It is adjusted on test to give a deflection of the oscilloscope equal to that caused by ± 75 kc/s deviation of the received carrier; its setting should not be disturbed unless a f.m. signal generator is available to provide a standard to which it can be re-set.

3.2. Summary of Operating Procedure

To set up the apparatus for the measurement of multipath signals, the routine is as follows:

1. Set the upper two controls to "A.G.C." and "Display".
2. Switch to "Set Zero", set the oscilloscope spot on the vertical centre line of the tube with the X shift control, and on the required zero base line with the Y shift control.
3. Switch to "Cal." and adjust the X gain control for a trace length of 5 cm. (The standard graticule is ruled in 0.5 cm squares).
4. Switch to "Operate" and tune to the required transmission, with the a.f.c. switched out. The oscilloscope display forms a tuning indicator, the correct tuning point being that at which the trace is centred horizontally. It must be emphasized that the receiver must not be tuned for a maximum reading on the signal-strength meter.
5. Adjust the Y gain control to centre the trace vertically about the centre line on the graticule.
6. Since the shift and gain controls of the oscilloscope are slightly inter-dependent, their settings should be checked and adjusted if necessary.

3.3. Interpretation of Display

When the apparatus is set up as stated in Section 3.2 the mean signal level is represented on the oscilloscope by the vertical deflection from the zero base line to the centre line of the graticule. In the absence of delayed signals the instantaneous amplitude remains constant as the carrier frequency varies and the oscilloscope trace is a horizontal straight line whose length is proportional to the peak deviation. If a reflected signal is received in addition to the direct signal, the phase difference between them, and hence the amplitude of their resultant, varies with the instantaneous frequency, and a trace of the type shown in Fig. 4 is obtained. This is a photograph of the oscilloscope display with an input including one delayed signal of amplitude 20% of that of the direct signal, with a path difference of 8 km; the carrier deviation is ± 75 kc/s at a modulation frequency of 120 c/s. The ratio of the amplitudes of the two signals is a/b and the path difference in km turns out to be equal to $2N$, where N is the number of complete cycles of amplitude variation in the total bandwidth of ± 75 kc/s. In general, several reflected signals are received simultaneously and the shape of the trace is more complicated. Fig. 5, for example, shows the trace resulting from a complex signal containing three delayed signals with path differences of 8 km, 16 km and 24 km. Signals containing even more components and producing more complicated displays are frequently encountered in practice. Nevertheless, it is often possible to deduce the amplitudes and path differences of the principal delayed signals with reasonable accuracy. The complex signals represented in Figs. 4 and 5 were produced with a laboratory multipath simulator which generates the reflected signals artificially using a magnetostriction delay line.²

Two limitations of the equipment which affect the accuracy of the display are the frequency responses of the i.f. amplifier and the Y deflection signal channel after the detector.

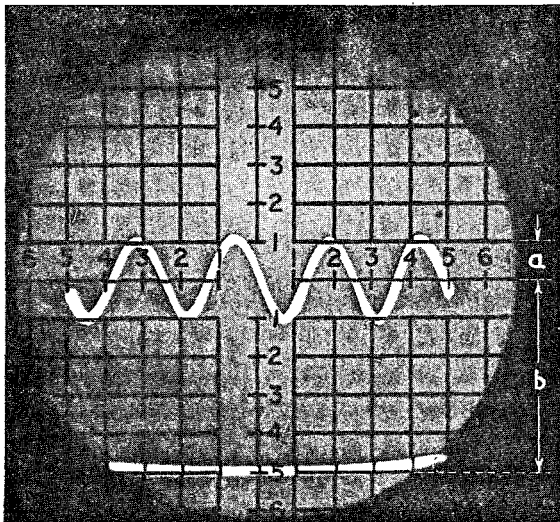


Fig. 4 - Display of complex signal;
one delayed signal, amplitude 20%
of direct signal, path difference 8 km

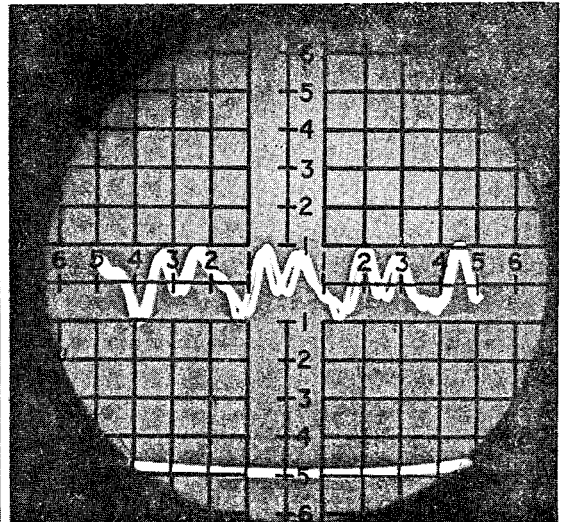


Fig. 5 - Display of complex signal;
three delayed signals each 10% of
direct signal, 8 km, 16 km and
24 km path differences

The shape of the amplitude/frequency response displayed on the oscilloscope is the product of that due to the propagation path and that due to the i.f. amplifier. It is therefore essential that the latter be flat within close limits over a bandwidth of at least ± 75 kc/s, and this should be checked at intervals to ensure that the response has not been impaired by valve replacement or drift in the tuned circuit components.

The amplitude modulation resulting from multipath propagation contains components which are high harmonics of the original modulation frequency. Because of the restricted bandwidth of the Y deflection channel, these components can be severely attenuated when the fundamental modulating frequency is high, particularly if the path differences of the principal delayed signals are also large; and this will reduce the apparent depth of amplitude modulation.

A source of difficulty in interpreting the display is doubling of the trace due to phase shift of the amplitude modulation. The display shown in Fig. 4 represents a low modulation frequency and a comparatively small path difference so that the forward and return traces are almost exactly superimposed. If either the modulation frequency or the path difference is increased, the reflected signal delay becomes a significant fraction of the frequency modulation period, resulting in appreciable de-phasing of the amplitude modulation and a doubling of the trace in the oscilloscope display.*

An additional cause of differential displacement of the forward and return traces is the phase distortion of the output of the discriminator which provides the X deflection voltage.

Both of these effects are inherent in multipath propagation and contribute more to the blurring of the display when receiving programme than any deficiencies in the phase characteristics of the equipment. Despite these limitations it has been found in practice that the display can be interpreted with reasonable accuracy.

4. PERFORMANCE

The results of performance tests on the first production model receiver are given below.

Tests Nos. 4.1 and 4.2 were carried out at a signal frequency near the middle of the tuning range; the sensitivity at the ends of the tuning range may drop by some 3 dB.

4.1. Sensitivity

In view of the specialist application of this receiver, the sensitivity is defined as the minimum signal input which will give an a.m. suppression ratio of 30 dB.

The measured value was $20 \mu V$.

*This is explained more fully in reference 2.

4.2. A.M. Suppression Ratio

("Display/Listen" switch in "Display" position and a.g.c. operating)

Input Carrier Level.	A.M. Suppression Ratio
30 μ V	35 dB
100 μ V	42 dB
300 μ V	42 dB
1 mV	40 dB
3 mV	40 dB
10 mV	40 dB

4.3. Modulation-Frequency Response (at audio output)

Fig. 6 shows the modulation-frequency response for a f.m. transmission to which the normal pre-emphasis (50 μ sec time constant) has been applied.

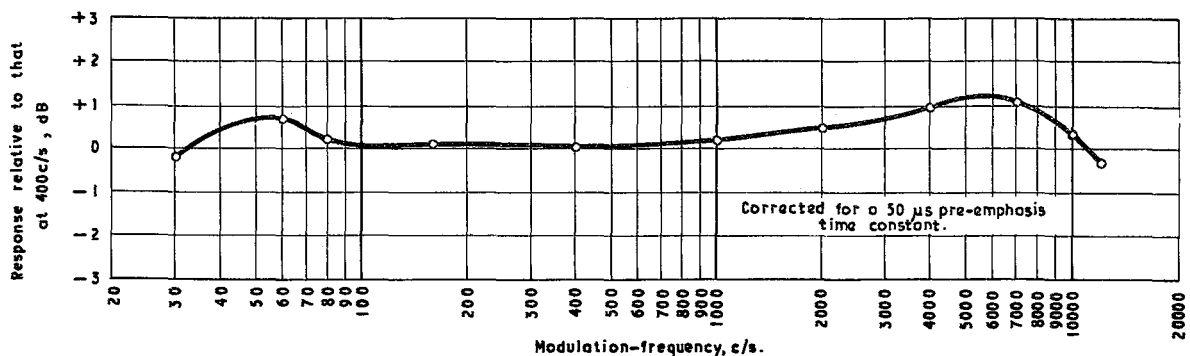


Fig. 6 - Modulation-frequency response

4.4. Total Harmonic Distortion

The total harmonic distortion at various power output levels, with ± 75 kc/s deviation at 400 c/s is:

500 mW	0.6%
1.0 W	0.8%
1.2 W	1.1%
1.5 W	9.5%

4.5. Frequency Response of Oscilloscope Display

Stray circuit capacitances cause the deflection of the oscilloscope trace in both axes to fall at the higher modulation frequencies. The frequencies at which the response has fallen by 3 dB are:

X deflection	9 kc/s
Y deflection	13 kc/s

5. CONCLUSIONS

The receiver has proved invaluable in both laboratory investigations of the effects of multipath propagation and at sites where poor reception has been experienced. In the latter case it provides a rapid check on the presence of reflected signals, a means of selecting the best location and orientation for the receiving aerial, and a standard of comparison to determine whether the receiver normally in use at the site has sufficiently good limiting to suppress the avoidable distortion associated with the a.m. component of the signal.

The receiver has been demonstrated to the British Radio Equipment Manufacturers' Association and models have been supplied to several departments of the B.B.C.

6. REFERENCES

1. "Multipath Propagation in Band II (88-95 Mc/s) and its effect on F.M. Reception—I", Research Department Report No. E-056, Serial No. 1956/39.
2. "V.H.F. Sound Broadcasting: Subjective Appraisal of Distortion due to Multipath Propagation in F.M. Reception", Research Department Report No. G-073, in preparation.